

A New Model for the Width of the Broad Emission Lines in AGN: The Role of the Accretion Rate

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We present a model which relates the Broad Emission Line Regions of AGN to the accretion mechanism. Based on the Keplerian assumption for the high velocity clouds of the gas responsible for the production of the Broad Emission Lines, we identify that gas with an outflowing disk/coronal wind forms a stabilized Shakura-Sunyaev accretion disk. We show that in the framework of this picture the observed range of $H\beta$ FWHM from Broad Line to Narrow Line type 1 AGN, is well reproduced as a function of the accretion rate.

Key words: galaxies: active; quasars: general

1 Introduction

The main facts about Broad Emission Line Regions (BELRs) of AGNs can be summarized as follow: **(a) Ubiquity:** Broad Emission Lines (BELs) are probably ubiquitous in AGN, being unobserved only when a good case exists for their obscuration by dust (type 2 AGN) or their being swamped by beamed continuum (Blazars). This suggests that the presence of Broad Emission Line Clouds (BELCs) in the AGN environment is closely related to the mechanisms which are responsible for the quasar activity. **(b) Photoionization:** reverberation studies of the BELs in many Seyfert 1 galaxies (e.g. Wandel, Peterson & Malkan, 1999: hereinafter WPM99) indicate that the gas of the BELCs is photoionized, and that its physical state, from one object to another, covers a rather narrow range of parameter space (in column density, electron density, ionization parameter). **(c) Virialization:** within a single object the BELCs are stratified, with the highest ionization lines being also the broadest (Krolik et al., 1991; Peterson et al., 1999). This accords with the photoionization hypothesis and with the idea that the BELs are broadened by their orbital Keplerian motion around the central source (Peterson & Wandel, 1999). **(d)**

Wide Range of Velocity: BELs do not at all have the same dynamical properties in all objects. A broad distribution of line widths from $\sim 1,000 \text{ km s}^{-1}$ (in Narrow Line Seyfert 1 galaxies, NLSy1) to $\sim 20,000 \text{ km s}^{-1}$ (in the broadest broad line type 1 AGN) is present.

Here we briefly present a model (Nicastro, 2000, hereinafter N00), based on the Keplerian assumption and which links the existence of the BELRs with the mechanism responsible for the quasar activity: accretion onto a massive black hole. Formulae, numerical details and definitions can be found in N00. The model explains naturally (a) the ubiquity of BELs in AGNs, and (b) the wide (but limited) range of velocities observed. Stratification in a single object can also be, at least partly, accounted for by this model.

2 The Model

We adopt the scenario described by Witt, Czerny and Zycki (1997, hereinafter WCZ97), and its recent revision (A. Rozanska and B. Czerny 2000, in preparation). These authors studied a radially co-accreting disk/corona system and demonstrated that a transonic vertical outflow from the disk develops where the fraction of total energy dissipated in the corona is close to the maximum, and for accretion rates higher than a minimum value, below which evaporation inhibits the formation of the wind. In the framework of this model, and consistent with the empirical quasar structure presented by Elvis (2000) at this conference, we propose that a vertical disk/coronal wind, is the origin of the BELCs and that the widths of the BELs are the Keplerian velocities of the accretion disk at the radius where this wind arises (N00). In our model the disk wind forms for external accretion rates higher than a minimum value $\dot{m}_{min}(m)$ (in critical units; see N00 for details) below which a standard Shakura-Sunyaev (1973, hereinafter SS73) disk (i.e. SS-disk) is stable and extends down to the last stable orbit. The model explains the observed range of FWHM in the BELs of AGN as a function of a single physical quantity connected with the AGN activity: the accretion rate.

Width of the Broad Emission Lines:

We adopt an average radius r_{wind} for the transonic outflow (and so for the BELRs), obtained by weighting the radial distance by $(1 - \beta)$, between r_{tran} and r_{max} (see equations 1-3 in N00 for appropriate definitions). In Figure 1 we show the relationship between the accretion rate (in the range $\dot{m}_{min}(m) - 10$) and the expected $\text{FWHM}(r_{wind})$ (solid, thick curves) and $\text{FWHM}(r_{max})$ (dashed, thin curves), for $m = 10^6, 10^7, 10^8, 10^9$ based on the Keplerian assumption. These curves are independent of the mass of the central black hole, and so they overlap in the diagram of Figure 1. However, for each curve, the maximum achievable FWHM depends on the mass, via the limit imposed by

the minimum external accretion rate $\dot{m}_{min}(m)$ needed for an unstable SS-disk to exist. At the bottom of the plot the four horizontal lines indicate these values of $\dot{m}_{min}(m)$. The parameter space between the dashed and solid curves of Figure 1 gives a range of ~ 1.4 in FWHM (i.e. ~ 2 in radius) for a given accretion rate, so allowing, at least partly, for a stratification of the BELCs in a single object. For accretion rates $\dot{m} < 0.2$ (sub-Eddington regime) the predicted FWHM are quite broad ($\gtrsim 4,000 \text{ km s}^{-1}$), and similar to those typically observed in broad line type 1 AGN (Figure 1). For $\dot{m} = 0.2 - 3$ (Eddington to moderately super-Eddington) the corresponding FWHM span the interval $\sim 1,000 - 4,000 \text{ km s}^{-1}$, which contains the value of FWHM = $2,000 \text{ km s}^{-1}$ used to separate normal type 1 AGN and NLSy1. Hence our model predicts that narrow line type 1 AGN accrete at higher accretion rates compared to broad line objects, as suggested by Pounds et al. (1995). However, the mass of the central black hole in NLSy1 does not need to be smaller than that of broad line type 1 AGN. No instability is possible for $\dot{m} \lesssim \dot{m}_{min}(m)$ thus providing an upper limit of $\sim 15000 - 20000 \text{ km s}^{-1}$ for the BEL FWHM.

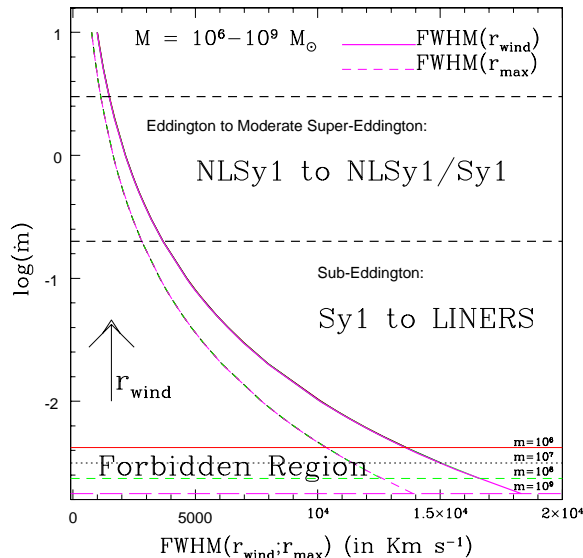


Fig. 1. Predicted accretion rate vs $\text{FWHM}(r_{wind})$, $\text{FWHM}(r_{max})$, for $m = 10^6, 10^7, 10^8, 10^9$, and \dot{m} in the range $\dot{m}_{min}(m) - 10$.

Relative Radiative Efficiency:

Using the predictions of our model, and the recent measurements of distances and FWHM reported by Wandel, Peterson and Malkan (1999) for a sample of 19 type 1 AGNs, we calculate the ratio ξ between the measured (WPM99) dimensionless luminosity $\ell = (L_{ion}/L_{Edd})$ and the predicted accretion rate. ξ is then a measure of the relative efficiency (compared to the maximum

radiative efficiency η : $\xi = \epsilon/\eta$, where $\epsilon = L_{ion}/\dot{M}c^2$) by which the accretion power is converted into ionizing luminosity. We found that ξ is correlated with the measured mass of the central black hole (see Figure 3 in N00). This observational result is not an obvious consequence of our model and needs further study. This correlation may explain why we do not see very-low mass AGN ($\lesssim 10^4 M_\odot$): the efficiency in converting accretion power into luminosity may be too low to observe such objects.

3 Conclusions

We presented a simple model which tightly links the existence of the BELCs in type 1 AGN to the accretion mechanism (N00). We identify the BELR with a vertically outflowing wind of ionized matter which forms at a critical radius in the accretion disk, consistent with the model for quasar structure presented by Elvis (2000) at this conference.

Our main findings are: (a) the entire observed range of velocities (FWHM) in type 1 AGN is naturally reproduced in our model by allowing the accretion rate to vary from its minimum permitted value to super-Eddington rates; (b) for accretion rates close to the Eddington value, the expected FWHM are of the order of those observed in NLSy1. Lower accretion rates give instead FWHM typical of broad line type 1 AGN. (c) We find an empirical relationship which suggests that the radiative efficiency of higher mass black holes is greater than that for lower mass black holes.

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